Testing Alternative Decision Approaches for Identifying Cleanup Priorities at Contaminated Sites

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This exploratory study compares two approaches for involving nonexpert stakeholders in difficult policy choices. Both approaches have as their goal informing members of the public about contaminated sites and involving them in decisions regarding their cleanup. The first approach focuses on technical information and seeks to improve the available knowledge base so that participants can make choices informed by detailed scientific data. This approach is similar in intent to many of the science-based initiatives in public involvement now being undertaken by EPA, DOE, and other federal or state agencies. The second approach, in contrast, focuses on values-oriented information and seeks to improve stakeholders' ability to make difficult choices in light of required tradeoffs across a variety of technical and nontechnical concerns. The results demonstrate that although both approaches help to increase participants' knowledge level, a values-based approach is more successful in terms of helping nonexpert participants to make decisions about what have historically been viewed as primarily technical problems.

1. Introduction

A key objective of the U.S. Department of Energy (DOE) is to support improvements in environmental quality by aggressively cleaning up the legacy of radiation contamination as a result of civilian nuclear research and the past production of nuclear weapons. The recent report, *Accelerating Cleanup: Paths to Closure*, discusses how the agency intends to meet this objective while being sensitive to concerns of the agency's stakeholders such as the cleanup workforce, nearby communities, regulatory agencies, and the general public (*1*). A central aspect of this accelerated cleanup initiative involves fostering a better understanding among all stakeholders—DOE and scientific experts included—of the technical requirements for meeting the agency's cleanup objectives and how they are shaped by health and safety, cost, environmental quality, and temporal constraints. Key to fostering this broader understanding is the inclusion in the cleanup process of techniques for ensuring an enhanced responsiveness to the concerns of stakeholders by engaging them in decision making processes that provide insight for setting cleanup priorities and implementing cleanup plans.

Despite its obvious appeal, involving stakeholders in setting DOE cleanup priorities is not an easy task. This cautionary tone is consistent with the perspective of a broad literature on stakeholder participation, public involvement in risk management decisions, and dispute resolution (*2, 3*). It is also consistent with the decidedly mixed real-world results from recent initiatives to clean up or store hazardous and nuclear wastes. A good example is the effort to involve states in the management of long-term storage of commercial low-level radioactive wastes (*4*). Despite the expenditure of more than $600 million and numerous suggestions as to how to organize and promote public consultation processes, none of the efforts to establish a regional compact have been successful (*5, 6*). As a result, most wastes continue to be stored on-site or in temporary storage facilities, which represents a highly visible, and potentially dangerous, failure of public policy.

In our view, many of the failures associated with recent DOE consultation initiatives are richly deserved. In particular, problems appear to stem from the absence of an approach that permits participants to think (and feel) carefully about the different pros and cons of policy options and then, once their own priorities are in order, to be involved meaningfully in the development of a recommended alternative. In consequential decision contexts such as the cleanup or storage of radioactive wastes, meaningful involvement goes well beyond inviting a cross section of people to receive and respond to technical information about a specific problem (*7, 8*). There must also be mechanisms in place to improve the participants' ability to recognize and comprehend key facets of the problem and make difficult choices about how the cleanup effort should proceed. Clearly, informing these difficult choices involves careful consideration of the technical components of a cleanup problem and the anticipated consequences of different cleanup actions. A second and equally important aspect of informing choices, however, is the inclusion of stakeholders' values in a way that facilitates the creation of cleanup alternatives that directly and responsibly address their identified and varied concerns.

Large investments, in terms of public money and both public agency and private citizens' time, are being made with the hope that increased public involvement in difficult environmental policy decisions will lead to improved and more responsive outcomes that also meet regulatory requirements. The diversity, both in problems and in consultation techniques, is immense, and it is perhaps not surprising that reviews of these initiatives range from the generally encouraging (*9*) to the cautionary (*10*) and openly skeptical (*11*). In this large literature, however, there are few attempts to establish an experimental framework that explicitly compares different stakeholder-based approaches to the same problem.

Our objective in this exploratory study is to provide guidance to agency managers in the development of improved consultation processes by comparing two alternative approaches for involving stakeholders in choices about the cleanup of contaminated sites. Both approaches inform nonexpert members of the public about key elements of decisions relating to the cleanup of contaminated sites. The first approach focuses on the presentation of technical information and seeks to improve the available knowledge

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TABLE 1. Experimental Design

science-based	values-based
introduction	introduction
initial self-rating	initial self-rating
background information	background information
·radiation	·radiation
·three contaminated sites	·three contaminated sites
·ongoing cleanup efforts	·ongoing cleanup efforts
·the town of Larkspur	·the town of Larkspur
summary table (Table 2)	summary table (Table 2)
specific information	specific information
1. specific radiation levels in soil by particle type (α, β, Γ, X) and severity (millirem)	1. general environmental effects by indicator species
2. specific radiation levels in water by particle type (α, β, Γ, X) and severity (millirem)	2. general human health effects in terms of illness or death
3. human heath effects by ailment and severity	3. values components (economic costs of monitoring, tourism losses, unsightliness)
4. environmental health effects by type, severity, and ecosystem	4. magnitude of soil and water contamination (x "normal")
summary table (Table 3)	summary table (Table 4)
no intervening value-structuring task	intervening value-structuring task: modified swing-weighting approach
choice task 1 − no uncertainty	choice task 1 − no uncertainty
intervening self-rating	intervening self-rating
choice task 2 − with uncertainty	choice task 2 − with uncertainty
intervening self-rating	intervening self-rating
choice task 3 − direct allocation	choice task 3 − direct allocation
final self-rating	final self-rating
close and payment	close and payment

base so that participants can make choices that are informed by detailed scientific data. This approach is similar in intent to many of the science-based initiatives in decision making now being undertaken by EPA and other federal or state agencies as well as DOE (*12−14*). The second approach also provides scientific data but, in addition, presents values-oriented information that seeks to improve the ability of nonexpert participants to make difficult tradeoffs across a variety of technical and nontechnical concerns. This approach is modeled on several decision-aiding initiatives that emphasize value-focused techniques (*8, 15, 16*). Although the basic factual information conveyed to participants in the two conditions is identical (e.g., progress of the cleanup efforts and site characteristics, contamination levels, environmental and human health effects), both the form in which technical data is presented and the attention given to values-based decision aids for participants are quite different.

We anticipated that participation in either the science- or values-based conditions would lead to subjects making more informed choices, as measured by their (self-reported) level of knowledge, their degree of comfort with decisions, and how well their choices were felt to reflect their concerns. We were also interested in how subjects' affective reactions to the different sources of contamination would influence their choices, as measured by the desired intensity of the cleanup effort and the size of the funding allocation for a selected contaminated site. We anticipated that allocation choices made by subjects in the science-based condition would reflect their affective judgments more strongly than those in the values-based condition. We also hypothesized that the values-based subjects would make choices that more closely reflected their stated priorities about how cleanup efforts should proceed.

2. Methods

2.1. Context. The context for this experiment was the cleanup of Federal Superfund sites contaminated with low dose radiation. Specifically, participants were asked to provide input to decisions about how public funds should be allocated to the cleanup of three hypothetical sites in the Pacific Northwest. These sites were as follows: a former nuclear weapons facility, an irrigation-tunneling project with radon emissions, and a storage depot for farm fertilizers containing trace amounts of radioactivity.

All subjects were provided with short written descriptions of each of the three sites as well as a map depicting the locations of the three sites in relation to the fictitious town of Larkspur. Participants were told to assume that they lived in the town and planned to continue doing so. They were then asked to help allocate \$30 million in cleanup funds across the three sites; \$30 million was said to be the spending level proposed for year five of an anticipated 8-year cleanup effort. To avoid a bias in favor of completing the cleanup at the cheapest of the three sites, participants were told that completely cleaning up any site would not be possible even if the entire \$30 million budget were to be spent at one location.

2.2. Design. This experiment made use of a workbook prepared in two versions, which are referred to as the *science-based* and the *values-based* conditions (Table 1). Both versions of the workbook consisted of 23 pages and provided specific information to subjects about the human and environmental health risks of radiation as well as the principal issues and problems associated with cleanup at the contaminated sites. Additional material was included in the form of color-coded charts and tables presented on the wall of the room where the study took place; these charts and tables allowed participants to study the detailed characteristics of different cleanup options at their own pace. Subjects recorded their answers to a series of closed-ended questions and decision tasks in the workbooks. Individuals worked one-at-a-time under the supervision of a trained facilitator at a data services laboratory in Eugene, OR. Both workbooks required approximately 1 h to complete.

The experiment had a multipart design with one independent variable (the science-based or values-based structure) and several dependent variables. The dependent variables used for judging the effectiveness of the two

TABLE 2. Background Information about Each of the Three Contaminated Sites[a]

	nuclear weapons facility	irrigation tunnel project	fertilizer depot
level of soil contamination within 100 m of site (millirem/year):	3600	1800	720
*average annual human exposure = 360 millirem/year			
level of water contamination within 100 m of site (millirem):	240	120	48
*normal "background" level = 28 millirem			
average number of people who venture onto site per year:			
visitors (authorized and unauthorized)	500	10	1000
cleanup personnel	225	40	40
regular personnel/staff	15	5	75
percent of site remaining to be cleaned after year 5:	50%	70%	65%
proximity of site to town of Larkspur:	5 miles north	3 miles west	0.5 miles south
total size of site:	14 acres	1 acre	2.5 acres
total cost to complete cleanup as of year 5:	$80 000 000	$45 000 000	$35 000 000
projected time to finish cleanup at current rate of work (in years):	7	4	2
intended purpose of the site (post-cleanup):	wildlife refuge	rangeland	storage warehouse

[a] This information was presented in both the science-based and values-based conditions.

TABLE 3. Specific Information about Each of the Three Contaminated Sites Presented Only in the Science-Based Condition

	nuclear weapons facility	irrigation tunnel project	fertilizer depot
level of soil contamination within 100 m of site (millirem):	3600	1800	720
*average annual human exposure = 360 millirem/year			
level of contamination (millirem) from:			
alpha particles	450	575	25
beta particles	1750	1150	450
gamma rays	1050	75	245
X-rays	350	0	0
level of water contamination within 100 m of site (millirem):	240	120	48
*normal "background" level = 28 millirem			
level of contamination (millirem) from:			
alpha particles	5	10	10
beta particles	135	92	33
gamma rays	70	18	5
X-rays	30	0	0
environmental health impacts (measured as the number of animals/plants with radiation-related abnormalities per 100 sampled) within 1 square miles of site on:			
plants	20	7	2
terrestrial vertebrates	30	17	2
aquatic vertebrates	5	2	0
health effects (measured as the mean number of radiation-related illnesses/deaths per 1000 workers and visitors to the site over the total 8 year cleanup time):			
respiratory infections	10	6	25
nonfatal cancers	10	5	15
radiation sickness	2	0	0
nonfatal bone disease	5	4	5
genetic effects	5	2	5
radiation-related deaths	4	1	0

decision-aiding treatments included participants' self-ratings of their knowledge level, their level of comfort with their decisions, and their perception of how well their stated choices reflected their concerns. Participants were asked these questions at several different times over the course of the study so that we could compare their initial and final responses and also test for the effectiveness of particular interventions.

Both the science-based and values-based conditions shared four common elements. These elements were (1) background information about radiation, the contaminated sites, the ongoing cleanup efforts, and the hypothetical town of Larkspur, (2) more detailed information about the human and environmental health risks of radiation, (3) closed-ended self-rating questions, and (4) a series of three related choice tasks (Table 1). The information about the three contaminated sites was further broken down into information dealing with radiation levels in surrounding soils and water, the expected number of people who would be entering each site, the percentage of the site remaining to be cleaned, the proximity of each site to the town, the remaining cleanup costs, and the amount of time remaining to complete the cleanup effort (Table 2). Providing all participants in both conditions with the data shown in this table ensured that everyone would have access to the same basic information about the cleanup options.

Both the values- and science-based workbooks provided specific information about the status of cleanup activities at each of the three contaminated sites. However, the way this information was presented varied between the two different treatments. In the science-based condition, subjects were presented only with technical information relating to the level of contamination and the human and environmental health risks at each of the three sites (Table 3). This information had been pretested for comprehension and completeness as part of parallel risk-communication studies

TABLE 4. Specific Information about Each of the Three Contaminated Sites Presented Only in the Values-Based Condition

	nuclear weapons facility	irrigation tunnel project	fertilizer depot
overall environmental risks within 1 square mile of site: (0 = no risk; 5 = moderate risk; 10 = extreme risk)	7	4	1
percent of alder affected within 1 square mile of site	20%	7%	2%
percent of deer affected within 1 square mile of site	30%	17%	2%
percent of brook trout affected within 1 square mile of site	5%	2%	0%
risk of radiation-related illnesses to humans: (0 = no risk; 5 = moderate risk; 10 = extreme risk)	4	2	10
percent of workers and/or visitors falling ill	3.2%	1.7%	7.0%
risk of radiation-related deaths to humans: (0 = no risk; 5 = moderate risk; 10 = extreme risk)	3	1	0
percent of workers and/or visitors dying	0.04%	0.01%	0.0%
annual costs of managing the Larkspur drinking water supply	$1 000 000	$2 000 000	$250 000
annual costs to the Larkspur economy from reduced tourism due to contamination:			
summer tourism (camping, fishing, etc.)	$750 000	$5 500 000	$0
percent decline	3%	22%	0%
winter tourism (skiing, snowshoeing, etc.)	$1 500 000	$15 000 000	$0
percent decline	4%	36%	0%
judged unsightliness ("ugliness") of site: (0 = not at all unsightly; 5 = moderately unsightly; 10 = extremely unsightly)	8	6	2
level of soil contamination within 100 m of site (x normal level): *average annual human exposure = 360 millirem/year	10.0 x	5.0 x	2.0 x
level of water contamination within 100 m of site (x normal level): *normal "background" level = 28 millirem	10.0 x	5.0 x	2.0 x

conducted by colleagues working on this DOE-sponsored research (*17*). In the present study, subjects were presented with information that described contamination levels by radiation type and severity in millirem (e.g., alpha particles, beta particles, gamma rays, and X-rays), risks to human health (frequency of respiratory ailments, cancers, radiation sickness, genetic effects, and fatalities among people visiting and working at each site), and environmental risks (frequency of radiation-related defects in plants and terrestrial and aquatic organisms).

In the values-based condition, information as it related to the severity of contamination at each of the three sites was linked explicitly to societal values and to personal objectives for the cleanup activities (Table 4). For example, human health risks were described in terms of the general severity of anticipated effects (i.e., using scales from 1 [low severity] to 10 [high severity]) and were not subdivided by the type of ailment, as was the case in the science-based treatment. Environmental risks were presented using 10-point scales that addressed anticipated changes in the levels of indicator species in each of the three communities (alder, deer, and brook trout). Other aspects of the site cleanup activities were linked to the costs of ongoing monitoring, to losses of tourism-related revenues due to the radiation contamination and ongoing cleanup operations, and to the unsightliness of the cleanup at the sites.

Consistent with implementing a decision framework based on stakeholders' values, the values-based workbooks included a structuring task designed to help participants think through difficult tradeoffs associated with allocating the year 5 cleanup funds. Participants were asked to consider the six different values-based components noted above and to decide which of these concerns was relatively more or less important to them. These participants employed a modified swing-weighting approach (*18*) in which each individual was provided with the range of anticipated effects, showing the worst and best levels for each value objective. They were then asked to rank these six areas of concern by first selecting the value they would most like to improve (i.e., "swing") from the worst to the best possible level, then to select the second most-important value, and so forth. Using this approach, all six value categories were ranked from most to least important.

Subjects in both conditions were then asked to make choices during three different decision tasks. The first and second tasks asked each person to choose their preferred allocation of funds across the three sites from a list of five prepared alternatives where the funding allocations totaled $30 million and were $5, $10, or $15 million for each individual site. The anticipated outcomes of these funding allocations (the parameters shown in Tables 3 and 4) were scaled accordingly and were reflected as changes in the attributes that were presented as part of the second summary table in both the science-based (Table 3) and values-based (Table 4) conditions. The difference between the first and second choice tasks was that the latter task introduced uncertainty (by showing a range of possible consequences for each anticipated outcome) about the magnitude of effects so as to increase its realism. To help facilitate easier comparisons across the alternatives during both of these choice tasks, the five alternatives along with the current status of each site were presented side-by-side on 3′ × 5′ tables affixed to the walls of the room where the study took place.

The third choice task asked subjects to directly allocate funds themselves using a self-updating computer model in which the anticipated outcomes of the cleanup effort were updated in real-time depending on the size of the desired allocation. The computer model allowed subjects to immediately see the anticipated effect of their choices and, if desired, to change the allocations in order to improve the balance (that is, make the relative allocations more compatible with their preferences) across the sites.

At the close of the first self-rating, subjects were asked to provide affective judgments for each of the three contaminated sites. Recent findings in judgment and choice research acknowledge the importance of emotions and affect—the feeling states that people experience, such as happiness or sadness, and the qualities associated with a stimulus or event, such as its perceived goodness or badness—as key elements in how individuals form judgments and make decisions (*19,*

TABLE 5. Closed-Ended Self-Rating Questions Used in Both the Science-Based and Values-Based Conditions[a]

question 1[b,d]	Do you think policy decisions about the cleanup of contaminated soils as part of the Superfund program should be based just on public input or should they be made just by technical experts? 1 2 3 4 5 6 7 just public input — both public and expert input — just expert input
question 2[b,c,d]	How would you characterize your level of knowledge about radiation risks? (very little knowledge; moderate amount of knowledge; a lot of knowledge)
question 3[b,c,d]	To what extent do you trust risk managers working for the government to do a good job on the cleanup of contaminated soils? (I do not trust them at all; moderate amount of trust; I trust them very much)
question 4	How well does your choice on the previous page match with what you believe would be the ideal allocation of funds for the cleanup of the contaminated sites in year five? (not at all well, moderately well; very well)[c,e]
	How well do you feel that the choices you made today about funding allocations reflect what you really care about when it comes to the cleanup of contaminated sites? (not at all well, moderately well; very well)[d,f]
question 5[d]	To what extent do you feel that the information presented to you today was distorted to suit the needs of the government managers in charge of cleaning up the contaminated sites in your community? (not at all distorted; moderately distorted, very distorted)
question 6[d]	How useful did you find the information that was presented to you today to be for making your choices about the Superfund cleanup of the contaminated sites? (not very useful; moderately useful, very useful)

[a] Subjects' answers were expressed on seven-point Likert scales as shown after question 1. Scale end and mid-point(s) for the other questions appear in parentheses. [b] Question asked at start of experiment. [c] Question asked after choice task 1. [d] Question asked after choice task 3. [e] Question version 1. [f] Question version 2.

20). In this study we elicited affective judgments across two dimensions, valence and arousal for each of the three contaminated sites where valence was measured using a seven-point scale from very good to very bad (using "indifferent" as a midpoint) and arousal was measured using a seven-point scale from very calm to very upset (with "indifferent" again a midpoint).

Each workbook ended as it began, with a series of closed-ended self-rating questions where responses were provided on seven-point Likert scales. Both of the middle choice tasks also were followed by similar closed-ended self-rating questions. Three specific questions were only asked at the termination of both the science-based and values-based conditions. These questions asked for participants' opinions about the quality and level of distortion of the information that was presented to them as well as its usefulness in terms of informing their cleanup choices; the exact wording all of the self-rating questions is shown in Table 5.

2.3. Subjects. The subjects in this study were paid adult volunteers randomly selected for either the values- or science-based treatments from a subject pool maintained by a data services laboratory in Eugene, OR. Fifty subjects participated, half in the science-based condition and half in the values-based condition. Subjects were reminded that there were no right or wrong answers to any of the questions and that their responses, although anonymous, would help to provide insight to government decision makers about an important and problematic series of public policy questions.

2.4. Data Analysis. Analyses were carried out on the data obtained from the closed-ended questions and choice tasks in subjects' completed workbooks in both the science- and values-based conditions. The samples (25 subjects in the science-based condition and 25 subjects in the values-based condition) are relatively small but not unusual for an exploratory study of this type. Descriptive statistics were used to summarize and compare subjects' responses to the closed-ended self-rating questions. For questions that were asked only twice over the course of the experiment, 1-tailed paired-sample t-tests were used for within-subject comparisons and two-sample t-tests were used for between-subject comparisons. Repeated measures analyses of variance were used for within-subject questions that were asked three times.

3. Results

Participants in the science- and values-based conditions were very similar in their judgments about their desired level of public and expert participation for choices about site cleanup (Table 6, item 1). At the start of both conditions, subjects' expressed preference for the level of expert and public input was 4.48, coinciding with a roughly equal blend of public and expert input. These levels changed little by the end of the workbooks, with a mean rating of 4.52 in the values-based condition and 4.60 in the science-based condition. Neither of these differences is statistically significant.

Responses to the self-rating questions showed that subjects in both the science- and values-based conditions felt more knowledgeable after completing their respective workbooks relative to when they started (Table 6, item 2). For subjects in the values-based condition, their mean initial knowledge level of 3.56 rose to 4.40 after the first choice task and then fell to 4.28 following the third choice task (which introduced uncertainty into the consequence estimates). From beginning to end, these participants' mean level of (self-reported) knowledge rose by 0.62 points, a statistically significant difference at the 0.05 level. Subjects in the science-based condition began with a base level of knowledge of 3.32, which rose by a statistically significant margin to 4.84 after the first choice task and then fell to 4.48 following the

TABLE 6. Summary of Within-Condition Comparisons of Participants' Responses to Closed-Ended Questions Asked at Three Points during the Science-Based and Values-Based Conditions (Unabridged Questions Appear in Table 5)

question	Science-Based							Values-Based						
	$\bar{x}_{Start}$	SE_{Start}	$\bar{x}_{Mid}$	SE_{Mid}	$\bar{x}_{End}$	SE_{End}	p	$\bar{x}_{Start}$	SE_{Start}	$\bar{x}_{Mid}$	SE_{Mid}	$\bar{x}_{End}$	SE_{End}	p
1. public or experts?[d]	4.48	0.18			4.60	0.19	0.57	4.48	0.16			4.52	0.13	0.74
2. level of knowledge?[c]	3.32	0.32	4.84	0.27	4.48	0.24	$\ll$0.01[a]	3.56	0.28	4.40	0.25	4.28	0.27	$\ll$0.01[a]
3. trust in government managers?[c]	4.00	0.25	3.92	0.22	4.16	0.27	0.41[a] 0.58[b]	3.12	0.36	3.44	0.23	3.72	0.27	0.11[a] 0.04[b]
4. Choice reflects what matters?[d]			4.84	0.29	5.44	0.24	0.02			3.88	0.33	4.96	0.27	$\ll$0.01
5. Distortion of information[e]					2.40	0.21						3.28	0.34	0.03
6. Usefulness of information[e]					5.36	0.26						5.20	0.27	0.67

[a] p-level reflects the comparison of means at the start and end of each condition. [b] p-level represents results from a paired-sample t-test comparing means at the start and end each condition. [c] Repeated measures ANOVA for within-subject comparisons. [d] Paired-sample t-test for within-subject comparisons. [e] 2-sample t-test for between-subject comparisons.

third choice task; the comparison of initial and final knowledge levels is again statistically significant ($p \ll 0.01$). Overall, the mean reported knowledge level of the values-based participants increased 17% as compared to a 35% increase for the science-based subjects. However, three-way comparisons between the value- and science-based participants' initial, intermediate, or final ratings reveal no statistically significantly differences ($p > 0.05$).

One of the key questions asked of participants in both conditions was their level of trust in the ability of risk managers working for the government to do a good job cleaning contaminated soils (Table 5, question 3). The values-based participants show a steady increase in their expressed level of trust after choice tasks 1 ($\bar{x} = 3.25$), 2 ($\bar{x} = 3.44$), and 3 ($\bar{x} = 3.72$). A repeated measures ANOVA reveals no statistically significant difference between these means ($p = 0.11$), due largely to the small sample size. A paired-sample t-test comparing means after choice task 1 and choice task 3 revealed a statistically significant difference at the 0.04 level (Table 6, item 3). Participants in the science-based condition, on the other hand, show a more erratic pattern, with expressed mean levels of trust declining following choice task 2 (from $\bar{x} = 4.00$ to $\bar{x} = 3.92$) and then increasing after task 3 ($\bar{x} = 4.16$). Neither of these differences is statistically significant using repeated measures ANOVA or a paired-sample t-test comparing means after choice task 1 and choice task 3.

In terms of their feelings about the degree to which information presented to them was distorted to suit the needs of government managers (Table 5, question 5), subjects in the values-based condition judged the level of distortion to be higher ($\bar{x} = 3.28$) than their counterparts in the science-based condition ($\bar{x} = 2.40$). This difference was statistically significant ($p = 0.03$; Table 6, item 5). However, no statistically significant difference was observed for subjects' judgments about the usefulness of the information for informing cleanup choices (Table 6, item 6).

Another key question asked of participants following choice tasks 1 and 2 dealt with how well their choices about the cleanup of contaminated sites reflected what mattered to them (Table 5, question 4). For subjects in the values-based condition, mean responses increased from 3.88 to 4.96, a statistically significant difference at the $p \ll 0.01$ level (Table 6, item 4). Subjects in the science-based condition also show an increase in terms of how well the later allocations, which followed the introduction of additional information, reflected their values. This difference, from 4.84 at the start to 5.44 at the end, is statistically significant ($p = 0.02$). The reader will note that the initial ratings for the science-based participants are significantly higher (4.84 vs 3.88, $p = 0.03$) than those of the value-based participants. This result is puzzling—this question was asked at the very start of the questionnaire, before the introduction of any differences between conditions—and appears to be an artifact of the relatively small sample sizes. It is noteworthy that by the second set of self-ratings, completed toward the end of the study, there was no significant difference between the two means. In terms of absolute increases, however, the mean rating for participants in the value-based condition increased more than twice as much (28% as compared to 12%) over the course of the tasks introduced in the workbook.

TABLE 7. Summary of Affect Ratings Across the Valence (A) and Arousal (B) Dimensions in Both the Science-Based and Values-Based Conditions[a]

condition	$\bar{x}_{Nuclear}$	SE	$\bar{x}_{Fertilizer}$	SE	$\bar{x}_{Tunnel}$	SE
(A) Valence Dimension:						
science-based	6.36	0.19	4.52	0.26	2.28	0.28
values-based	6.08	0.17	5.08	0.22	2.16	0.24
(B) Arousal Dimension:						
science-based	6.36	0.22	4.28	0.22	2.48	0.30
values-based	6.32	0.22	4.44	0.28	3.02	0.23

[a] Answers represented on 7-point Likert scales from 1 = very good to 7 = very bad (midpoint = indifferent) for valence and 1 = very calm to 7 = very upset (midpoint = indifferent) for arousal.

For both conditions, subjects' highest affect ratings across the valence and arousal dimensions corresponded to the nuclear weapons facility, followed by the fertilizer depot and the tunneling project, respectively (Table 7). Mean funding allocations also were compared to subjects' affect ratings for each of the three sites. In the science-based condition, a steady increase in the size of subjects' desired funding allocations was observed as affect ratings across both dimensions—valence and arousal—increased (Figure 1A,B). In contrast, no such trend was observed for subjects in the values-based condition. However, the mean funding allocations of subjects in the values-based condition correlated well with the sites where the anticipated outcomes reflected the priorities identified during the values structuring task (Figure 1C). [Comparing subjects' identified priorities with their funding allocations was possible only for subjects' responses in the values-based condition because only they completed the modified swing-weighting task.]

4. Discussion

Our objective for this experiment was to study two approaches for involving nonexpert stakeholders in what historically have been considered technical choices, to be addressed by experts. The science-based approach focused on providing subjects with detailed factual information, leading to a statistically significant increase in reported knowledge level from the beginning of the workbook to the end. The values-

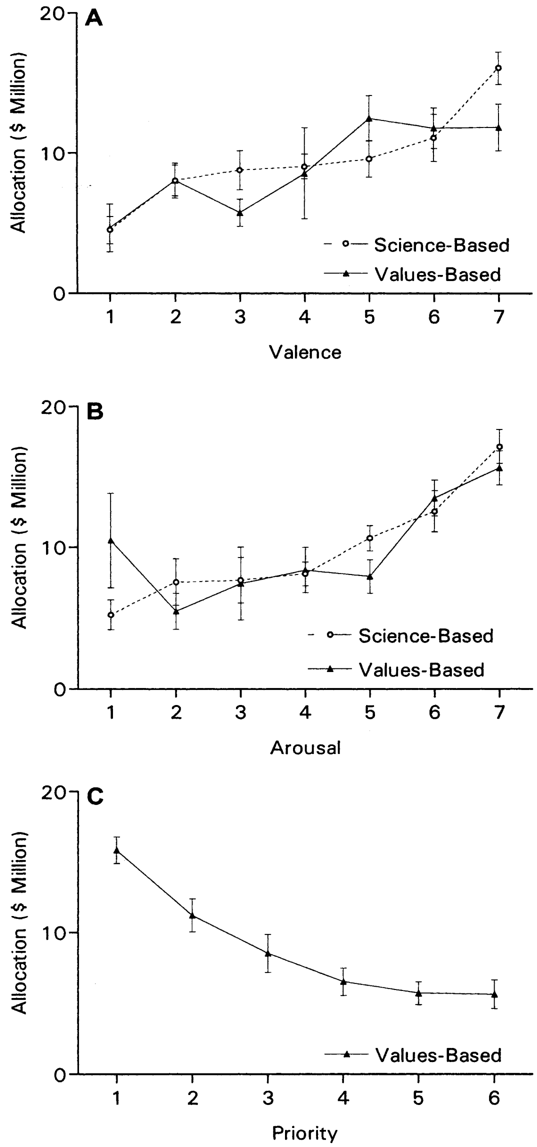

FIGURE 1. Subjects' mean funding allocations with respect to their affect ratings of valence (A) and arousal (B) as well as values-based subjects' priority ratings (C). Error bars reflect standard error.

based approach tied the same technical information (also leading to a statistically significant increase in reported knowledge level) to prioritized values (including both individual and societal objectives) so as to foster clearer, more consistent tradeoffs. As in most other real-world survey and elicitation settings, both approaches were constrained: the risks described to respondents were hypothetical (rather than experienced) and the amount of time that participants could devote to introspection and deliberation was limited.

As individual decision-aiding approaches to be utilized by stakeholders working alone or in groups, both the science- and values-based approaches show promise in terms of meaningfully engaging stakeholders in helping to set cleanup priorities. For example, both the science-based and values-based approaches resulted in a statistically significant increase in subjects' accumulated level of (self-reported) knowledge, comfort with their choices, and a feeling that their decisions reflect "what matters" (Table 6, items 2−4). These results are consistent with both workbooks providing subjects with a helpful structure for interpreting data. This structuring of the decision involved presenting alternatives that could be evaluated across several different attributes, reducing subjects' cognitive demands by implementing a step-by-step approach for analyzing a complex problem, enhancing evaluability (*21*) by allowing for a side-by-side comparison of the alternatives [for choice tasks 1 and 2], and providing real-time updates based on subjects' funding allocations [in choice task 3]) which afforded opportunities for learning.

Presenting information in a way that is helpful for making complex choices may also account for subjects' increased trust in the capabilities risk managers in government agencies (Table 6, item 3). Issues related to trust are a major problem for many federal agencies involved in waste cleanup activities, including DOE; low levels of trust and a corresponding decline in confidence have been highlighted as an impediment to the progress of cleanup activities and, at a deeper level, "call into fundamental question the bond between those who govern and those who are governed" (*12*). The results of this study (Table 6, item 6) show moderate increases in trust for the science-based subjects but statistically significant beginning-to-end increases in trust for the values-based participants. These results are supported by those of other values-based risk communication initiatives (*8, 22*). They also are consistent with, and help to explain, the finding of the current study (see Table 6, item 1) that subjects believe that important public policy decisions that affect them ought to include about an equal blend of expert and public input.

The results of this study also highlight several important differences in the design and outcomes of the science- and values-based approaches. Subjects' mean responses to one of the self-rating items show that participants in the values-based condition felt that the information presented to them was more distorted to meet the needs of government decision makers than did participants in the science-based condition (Table 6, item 5). We suspect that subjects in the values-based condition felt this way because a predominantly values-oriented treatment of contamination and cleanup issues was contrary to what was expected for an environmental problem that has its roots in complex technical principles and, therefore, requires a detailed science base. This supposition reflects the dominant societal paradigm concerning the key role of science in solving difficult technical problems such as those common to radioactivity and the cleanup of contaminated sites (*23*).

In this context, it is noteworthy that participants in the value-based condition reported a far-larger increase in the extent to which the two decision approaches helped to make choices about cleanup options that reflected what really matters to them over the course of completing the workbook (28% vs 12% for the science participants). This result is consistent with experimental evidence that people—including both experts and nonexperts—often have difficulty when asked to make complex decisions (*20*). When making choices based solely on technical information, the between-subject comparison suggests that at least a part of this difficulty stems from the fact that people tend not to place technical information in the larger context of helping them to define what matters. As a result, participants found it uncomfortable to make difficult choices involving science-science tradeoffs as part of the evaluation of alternatives.

For example, people in the science-based condition of the experiment were forced to make tradeoffs between various complex technical attributes of the alternatives (e.g., tradeoffs between reducing α or β particles and Γ or X-rays, tradeoffs between saving terrestrial vertebrates, aquatic vertebrates, or plants, and tradeoffs between a wide variety of frightening illnesses or death). These types of exclusively factual tradeoffs are extremely difficult to make and may represent a form of constitutive incommensurability (*24*), where individuals feel as though they are being asked to make tradeoffs among attributes that *all* seem critically important. People end up feeling as though they are forced to subvert some morally significant values in favor of others and this, understandably, creates a conflict. Evidence of tradeoff avoidance comes from results showing how participants in the science-based condition made their direct allocation choices (choice task 3). Increases in the mean allocation size were commensurate with increases in mean affect ratings across both the valence and arousal dimensions. On the other hand, the relationship between affect and allocation in the values-based condition was more erratic (Figure 1A,B). Overall, affective responses to the three contaminated sites were a more important driver of subjects' choices in the science-based condition, likely because these subjects were not explicitly told to consider their values and, hence, engaged in the well documented tendency of tradeoff avoidance (*24*, *25*).

In contrast, the magnitude of subjects' allocations in the values-based condition increased proportionally with the priority they assigned to addressing key attributes of the contamination (Figure 1C). For example, individuals who identified illnesses to humans as their number one concern during the modified swing-weighting task also allocated, on average, the most funds to the site where the number of illnesses was the most pressing problem—in this case the former fertilizer depot. Similarly, individuals who identified the costs associated with monitoring the town's water supply tended to allocate the most funds to the site of the irrigation tunneling project. The final priority-allocation relationship (Figure 1C) was established by calculating the mean funding allocations for all sites with the attributes corresponding to a particular priority rating (1−6).

In our opinion, choices about the cleanup of radioactive wastes (along with many other important public policy choices) that are reflective of subjects' carefully considered priorities are more thoughtful and, hence, of higher quality than choices based primarily on affect. Although we acknowledge the important role that affect plays in helping to simplify certain types of choices, we contend that complex choices that involve uncertain risks, benefits, and large expenditures of resources (like those common to the cleanup of contaminated sites) ought to proceed based on more thoughtful, deliberative modes of judgment. In this respect, participants in the values-based condition appear to have outperformed their peers who completed the science-based workbooks.

The values-based condition also has the ability to further democratize stakeholder-centered risk-assessment process by allowing nonexperts to participate more meaningfully. More meaningful participation is characterized by allowing nonexperts to more capably evaluate information and contribute in areas reflecting their own expertise (e.g., objectives relating to community stability and pride, quality of life, economic and recreation opportunities, and the like) (*16*). Moreover, structuring decisions in this way helps to address (and, in some cases, to resolve) issues of tradeoff avoidance because as the different attributes of a given alternative become more tractable, tradeoffs between them seem less objectionable. As a result, choices become easier and participants can begin to follow the mental and affective linkages leading from their own values to the selection of alternatives, which in turn increases their trust in the evaluation and allocation process.

Whereas it is proper for science information to come from technical experts, community and public stakeholders are the experts in terms of their own values. Thus, participatory decision-making processes should work to identify, structure, and meaningfully incorporate these values. Technical analyses are required to address the magnitude and incidence of consequences, but value judgments are needed to identify the sources of concern. Creating a more informed populace is an important objective of public participation processes, but it should be remembered that it is in turn a means to a more fundamental objective: helping nonexperts and experts alike to make choices about preferred cleanup alternatives that more closely reflect their primary concerns.

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